FORMED METAL ARMOR ASSEMBLY

Cross Reference To Related Application

[0001] This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Application 60/455,292 filed March 17, 2003, titled FORMED METAL ARMOR ASSEMBLY, which application is hereby incorporated by reference in its entirety.

BACKGROUND

[0002] The present invention relates to metallic armor and, more particularly, to a durable, formed metallic armor assembly for protection against multiple small arms bullets.

[0003] Various materials are used to make armor to protect against projectile penetration. Historically, metal-based armor was used for most armor applications. More recently, ceramic-based armor has been used for body armor, because of weight considerations. Metallic- or ceramic-based armor is typically used for coverings for vehicles. For ceramic-based armors, typically tiles of ceramic are bonded to a substrate and often secured in an outer cover to form a plate. The plates are then secured to a vehicle, or, in the case of body armor, placed in a fabric pocket. The plates may be designed to provide protection against a single penetration threat or against multiple penetration threats.

[0004] The penetration protection afforded by a particular armor must be balanced against weight constraints, particularly for body armor. One manner in which this balance has been achieved is by the use of relatively thin (less than 0.25 inch) ceramic facings with composite backing layers. Hard ceramics, such as silicon carbides or boron carbides, have been found necessary for the facings to allow weight efficient solutions.

[0005] The use of these ceramics with appropriate backing layer materials provides protection against multiple penetration threats. The use of metal plates, while providing protection against some penetration threats, is often disfavored because of the weight associated with the metal plates.

[0006] The hard, thin ceramics suffer from brittle fracture and cracking in use. Cracking of the ceramic facing prior to ballistic impact can result in ballistic failure of the armor in the field, an undesirable occurrence.

SUMMARY OF THE INVENTION

[0007] The present invention is an armor assembly with a durable, formed metallic material facing element combined with a backing portion to defeat multiple penetration threats at minimal weight while providing adequate durability for in field use. The formed metallic facing element preferably has a thickness of between about 0.02 inches and about 0.50 inches, a hardness no less than 30 on the Rockwell C scale, and the metal is formed in such a way that its effective density is reduced by at least about 20%.

[0008] The backing portion includes a fiber composite substrate with a thickness of between about 0.06 inches and about 3.00 inches, the substrate having at least one layer with a network of filaments having a tensile modulus of at least about 150 g/denier, an energy to break of at least about 8 j/g, and a tenacity of at least about 7 g/denier wherein the ratio of the thickness of the layer to an equivalent diameter of the filaments is no more than about 20.0.

[0009] There may also be an adhesive layer between the metallic facing element and the backing portion having a thickness of between about 0.0005 inches and about 0.090 inches. A protective outer cover also may be provided.

[0010] An armor assembly in accordance with the present invention is a durable yet light-weight armor assembly that can sustain multiple ballistic attacks without failure. The armor assembly may be used as a stand-alone armor or for use as ballistic inserts in conjunction with a ballistic vest and affords a new and useful manner of penetration protection against ballistic attack.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] In the accompanying drawings, which are incorporated in and constitute a part of the specification, embodiments of the invention are illustrated, which, together with a general description of the invention given above, and the detailed description given below, serve to exemplify the embodiments of this invention.

[0012] Figure 1 is a perspective view, partially broken away and partially in section, of one embodiment of an armor assembly in accordance with the present invention;

[0013] Figure 2 is a view in partial section of an embodiment of the present invention taken along line 2—2 of Figure 1;

[0014] Figure 3 is a perspective view, partially broken away and partially in section, of another embodiment of an armor assembly in accordance with the present invention;

[0015] Figure 4 is a perspective view of an embodiment of the present invention; and

[0016] Figure 5 is a perspective view of an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0017] The present invention is directed to an armor assembly having at least a formed metallic facing and a fiber composite substrate backing attached or adjacent thereto. It has been found that use of a formed metallic facing with the appropriate fiber composite substrate adjacent thereto provides a weight-efficient alternative to conventional ceramic-based facings adjacent to a composite substrate backing. Without intending to be limited by the description of preferred embodiments herein, the invention will be described in an exemplary manner as it relates to personal body armor, such as small arms protective inserts (SAPI).

[0018] Use of the term "metal" herein includes pure metal or metals, metal alloys, inter-metallic compounds, and mixtures thereof. Use of the term "ceramic" herein is defined as inorganic, nonmetallic materials, typically crystalline in nature, and generally are compounds formed between metallic and nonmetallic elements, such as aluminum

and oxygen (alumina—Al_2O_3), boron and carbon (boron carbide—B_4C), silicon and carbon (silicon carbide—SiC), and other analogous oxides, nitrides, sulfides, and carbides. Use of the term "or" herein is the inclusive, and not the exclusive, use. See BRYAN A. GARNER, A DICTIONARY OF MODERN LEGAL USAGE 624 (2d Ed. 1995). Use of the term "fiber" herein is defined as an elongated body, the length dimension of which is much greater than the dimensions of width and thickness. Accordingly, the term fiber as used herein includes a monofilament elongated body, a multifilament elongated body, ribbon, strip, and the like having regular or irregular cross sections. The term fibers includes a plurality of any one or combination of the above. The "equivalent diameter" of the fibers is the approximate average of the diameters of individual fibers in a layer of fibers.

[0019] Figure 1 illustrates an armor assembly 10 in accordance with the present invention in which a formed metallic armor assembly 12 includes a metallic facing element 14, an adhesive layer 16, and a composite fiber substrate/backing 18. The composite fiber structure/backing 18 may have one or more than one layer. Preferably, there is more than one layer. The metallic facing element 14 has a plurality of perforations 20. The assembly may include an encapsulating cover 22 with or without a rear portion 24, as illustrated in Figure 2.

[0020] The cover 22 may be constructed of any suitable conventional material, including nylon fabric, or may be a combination of materials, such as fabric, rigid plastic, and foam, that protects the formed metallic armor assembly 12 from wear-and-tear and provides added durability.

[0021] The formed metallic facing element 14 may be constructed of any suitable metals, including nickel, manganese, tungsten, magnesium, titanium, aluminum, copper, brass, bronze, and steel plate. Illustrative of useful steels are carbon steels which include mild steels of grades AISI 1005 to AISI 1030, medium-carbon steels of grades AISI 1030 to AISI 1055, high-carbon steels of the grades AISI 1060 to AISI 1095, free-machining steels, low-temperature carbon steels, rail steel, and superplastic steels; high-speed steels such as tungsten steels, molybdenum steels, chromium steels, vanadium steels, and cobalt

steels; hot-die steels; low-alloy steels; low-expansion alloys; mold-steel; nitriding steels for example those composed of low-and medium-carbon steels in combination with chromium and aluminum, or nickel, chromium and aluminum; silicon steel such as transformer steel and silicon-manganese steel; ultra high-strength steels such as medium-carbon low alloy steels, chromium-molybdenum steel, chromium-nickel-molybdenum steel, iron-chromium-molybdenum-cobalt steel, quenched-and-tempered steels, cold-worked high-carbon steel; and stainless steels such as iron-chromium alloys austenitic steels, and chromium-nickel austenitic stainless steels, and chromium-manganese steel.

[0022] Useful materials also include alloys such a manganese alloys, such as manganese aluminum alloy or manganese bronze alloy; nickel alloys, such as nickel bronze, nickel cast iron alloy, nickel-chromium alloys, nickel-chromium steel alloys, nickel copper alloys, nickel-molybdenum iron alloys, nickel-molybdenum steel alloys, nickel-silver alloys, or nickel-steel alloys; iron-chromium-molybdenum-cobalt-steel alloys; magnesium alloys; aluminum alloys such as those of aluminum alloy 1000 series of commercially pure aluminum, aluminum-manganese alloys of aluminum alloy 300 series, aluminum-magnesium-manganese alloys, aluminum-magnesium alloys, aluminum-copper alloys, aluminum-silicon-magnesium alloys of 6000 series, aluminum-copper-chromium of 7000 series, or aluminum casting alloys; aluminum brass alloys; and aluminum bronze alloys. Most useful are double hard steels, ballistic armor steels that meet the specifications set forth in Mil A 46100 and super high hard steels sold under the trade name Mars 240 and Mars 300 and Mars 300 Nickel Plus, available from Usinor Industeel. Steels that can be formed and hardened such as D2, A2, M4, PM-M4, Maximat150, S-5, S-7, Rex121, T15, M42, 4340, and spring steel are also useful.

[0023] Metals have long been known as good ballistic material, especially hardened metals. It is known to heat treat metal to increase its hardness and improve its ballistic performance. The use of metallic strike faces have been used where cost is important, but weight is secondary. Where weight is critical, ceramics, such as boron carbide, silicone carbide, or aluminum oxide, are used due their excellent performance and low weight. Historically, materials having the highest hardness to density ratios have yielded the most weight-efficient ballistic solutions when used as facing materials. Boron

carbide facings are conventionally used to produce the lightest armor assemblies, with silicon carbide facings producing slightly heavier assemblies, and aluminum oxide facings used where ultimate weight is not required and cost is important. The following table illustrates the hardness-to-density ratios for typical materials.

	Boron Carbide	Silicon Carbide	Aluminum Oxide	Armor steel
Hardness (Vickers)	3200	2300	1600	750
Density (g/cc)	2.5	3.2	3.98	7.8
Hardness-to-density ratio	1280	718	402	96.1

Table 1--Hardness-to-Density Ratios

[0024] Defeating multiple penetration threats, such as those defined by the United States military specifications for SAPI plates, have required the use of both a fiber composite backing and ceramic facing. Some penetration threats are more readily defeated by the hard facing and some penetration threats are more readily defeated by a fiber composite backing.

[0025] Conventionally, boron carbide facings with a composite backing or silicon carbide facings with a composite backing have been used to provide the desired multiple penetration protection. Surprisingly, applicant determined that by reducing the effective density of a high hardness steel, thereby increasing its hardness-to-density ratio to between about 120 and about 300, the steel can be made to perform similarly to boron carbide and silicon carbide assemblies with ratios of between 700 and 1300. Such reduction in effective density is realized by perforating the metal or other geometric forming of the strike face, as discussed in greater detail below.

[0026] Small arms rounds like the M-80 ball and the LPS ball are weight efficiently stopped by the use of fibrous backings alone. The 7.62 x 39 PS ball, the SS-109, the M-80 ball, and the LPS ball can be defeated at an areal density of 3.8 pounds per square foot (psf), without the use of a hard facing. To stop the M-855 projectile, however, which contains a hard core, additional material must be provided, which affects the ability to

meet the 5.1 psf weight requirement of the SAPI plate. Testing revealed that the most currently advanced backings, (e.g., raw material produced by Honeywell Corporation under the trade name Spectra Shield®) and molded at processing pressures of 3000 psi, yielded failures on the M-855 against the SAPI threats at the 5.1 pound per square foot areal density.

[0027] Testing the M-855 on a Mars 300 steel facing having a hardness of Rockwell C 55, adjacent the Spectra Shield® fiber composite backing, yielded the following results:

Facing	Backing	Result
.022 inch	4.1 psf	Fail
.040 inch	3.36 psf	Fail
.062 inch	2.45 psf	Fail
.080 inch	1.72 psf	Fail

Table 2--Solid Metal Test Results

[0028] Surprisingly, these failures can be reversed by forming the metal in a way that achieves a reduction in the effective density or a corresponding increase in metallic thickness for a given density, such as by perforation of the metal. This increase in hardness to areal weight (pounds per sq ft) or hardness to thickness by perforation in combination with sufficient advanced composite backing yields an armor assembly that can be as weight effective as boron carbide and silicon carbide ceramics based assemblies. This increases the specific hardness, or hardness-to-density ratio, of the metal.

[0029] While density is weight of the material divided by the displaced volume of the material, the effective density is the actual weight divided by the volume that the material would occupy if the material were solid between its outer dimensions. For example, in a facing of outer dimensions x (length), y (width), and z (thickness), the volume of the facing is x times y times z, and the density is the weight of the facing divided by this volume. In a perforated facing of the same outer dimensions, the effective density is the weight of the perforated facing (which is less than that of the non-perforated facing)

divided by the same volume (x times y times z), without accounting for the reduction in volume of the material that would be caused by the perforations.

[0030] Surprisingly, the holes in the metal perforation can be larger than the steel pin in the projectile and still provide acceptable results.

[0031] Increasing the fiber content of the backing material from the traditional 80% to a higher percentage, allows the fiber backing to work more weight efficiently in conjunction with the metallic facing.

[0032] Encapsulating the thin steel in a carbon fiber composite will increase its specific stiffness (stiffness to weight), which may also affect its effectiveness as a strike face.

[0033] It is known that steel armor can be made more weight effective by putting holes in the steel in a defined pattern and at a preferred spacing. Prior art also teaches that steel alone, when encased in rubber, can be an effective ballistic material. Moreover, the shape of the perforations can also have an effect on ballistic performance, especially when used in conjunction with additional perforated metal plates. Surprisingly, however, the use of a metallic facing element 14 having perforations along with a composite fiber substrate 18 is effective in providing protection against multiple penetration threats, as an alternative to a ceramic-based facing element.

[0034] For the present invention, optimization of hole pattern and spacing for every specific threat or group of threats that is anticipated may be conducted without undue experimentation, and will produce an armor assembly with minimal weight. The perforations may be round, square, hexagonal, slotted, etc., in any uniform pattern, a staggered pattern, or a random pattern without departing from the spirit or scope of the invention. For example, Figure 1 illustrates round perforations while Figure 3 illustrates square perforations. One embodiment of the present invention includes hole diameter of about 4mm, with the holes spaced about 6mm in a staggered pattern. Other embodiments include hole diameters of about 3mm to 3.5mm, with spacing of the holes about 4mm to about 4.5mm in a staggered pattern.

[0035] The perforations may be made in any conventional manner without departing from the spirit and scope of the invention. The perforations could be caused by expanding metal or cast at an obliquity to the surface of the armor plate. The perforations can be formed into the plate in the pre-hardened material and then hardened, or the steel can be hardened and the perforations formed with a laser or water-jet.

[0036] Surprisingly, when perforated metal materials are combined with fiber composite backings, as described below, the hole diameter can actually exceed the diameter of the core of the projectile and still be an effective armor assembly. This is possible because of the low probability of the core and the steel target lining up perfectly, and thus the desired effect on the projectile is accomplished as long as the core of the projectile touches any portion of the metallic strike face or side of the hole.

[0037] A preferred hole diameter for the present invention is less than 1.2 times the diameter of the core of the projectile that is to be defeated. A more preferred hole diameter is equal to the diameter of the core of the projectile that is to be defeated. A most preferred hole diameter is less than 90% of the diameter of the core of the projectile that is to be defeated. A hole diameter of about 3.2mm has been found to be effective for multiple penetration threats.

[0038] Preferably, the effective density of the metallic facing element 14 is reduced by at least about 20% compared to the solid, flat metal. But, the metallic facing element 14 need not be perforated to achieve the desired effective density reduction. Other geometric formations for the metallic facing element are also effective for reducing the effective density and providing the reduced weight of the metallic facing element 14. For example, Figure 4 illustrates an embodiment in which the metallic facing element 14 is provided with indentations 26 that do not completely penetrate the metallic facing element 14. Indentations 26 may be discrete, as in pits, or continuous, as in grooves, or a combination thereof, and may be in any or no pattern and of any shape, depth, or other dimension. Metallic facing element 14 may also be corrugated to reduce the effective density.

[0039] Also, Figure 5 illustrates pyramidal or conical projections 28 that are affixed to or formed as part of the metallic facing element 14. Projections 28 may be of any shape and the projections 28 may be arranged in any uniform pattern, a staggered pattern, or a random pattern. Other geometries may also be used without departing from the spirit and scope of the invention.

[0040] The areal weight of the metallic facing element 14 can be any value, and depends on the threat or group of threats that the element is to protect against. Preferably, at least 20% of the surface area of the metallic facing element 14 is perforated. The thickness of the metallic facing element 14 can be of any dimension, such as between about 0.02 inches and about 0.5 inches, and is tailored to the threats that are to be defeated. For the SAPI threat, a preferred thickness is less than about 0.125 inches, a more preferred thickness is less than about 0.10 inches and a most preferred thickness is less than or equal to about 0.080 inches.

[0041] For the SAPI threats, a preferred areal weight of the metallic facing element 14 is less than about 2.5 psf, a more preferred areal weight is less than about 2.0 psf, and a most preferred areal weight is about equal to 1.8 psf.

[0042] In a preferred embodiment of the invention for the SAPI plate, the hardness of the metallic facing element 14 is in excess of Rockwell C 25, is preferred to be in excess of Rockwell C 45, is more preferred to be in excess of Rockwell C 55, and is most preferred to be greater than or equal to Rockwell C 60.

[0043] In one embodiment, the metallic facing element 14 is a continuous monolithic plate that is generally flat. In other embodiments, the metallic facing element 14 has a single, double, or compound curvature.

[0044] In one embodiment, the metallic facing element 14 includes multiple individual plates made as described above that are arranged in a staggered or non-staggered array as tiles to cover the surface of the composite fiber substrate/backing 18.

[0045] The composite fiber substrate/backing 18 is any high performance backing involving a network of fibers with or without a resin matrix. Suitable backings include

composite ballistic laminates as described by U.S. Pats. No. 4,916,000; 5,677,029; or 5,443,883. The use of highly oriented tapes or films that are cross-plied at 0/90 degrees and laminated would also provide a suitable backing. The tapes or films also may have more than one ply or layer. If the tapes or films have more than one layer, the layers may be arranged such that lines of plies are disposed at angles greater than zero relative to the lines of adjacent plies.

[0046] Preferably, the thickness of the composite fiber substrate/backing 18 is between about 0.06 inches and about 3.00 inches, but any thickness is within the spirit and scope of the invention. The thickness of the backing 18 is preferably such that the ratio of the thickness of at least one individual composite layer of the backing to the equivalent diameter of filaments in the backing 18 is equal to or less than about 20.0, and most preferably between about 3.5 and about 10.0. The appropriate thickness for a particular application is determined based on the threat or threats to be defeated, weight considerations, cost considerations, and other considerations.

[0047] In one embodiment, the thickness of the backing 18 is at least 7 times the thickness of the metallic facing element 14. This will provide effective performance against selected penetration threats regardless of whether the metallic facing element 14 has a reduced effective density as provided above. Another embodiment effective against selected penetration threats is an assembly 10 in which the backing 18 has a thickness between about 4 and about 10 times the thickness of the metallic facing element 14. Preferably, the thickness of the backing 18 is between about 7 and about 9 times the thickness of the metallic facing element 14, and most preferably about 8 times the thickness of the metallic facing element 14.

[0048] These backings include fibers sold under the trademarks Spectra Shield® (Honeywell Corp.), Kevlar® (E.I. Du Pont de Nemours and Company), Twaron® (Teijin Limited), Vectran® (Celanese), M5® (Magellin Systems Int'l), Tensylon® (Integrated Textile Systems, Inc.), Borosilicate (E) glass fiber, S-2 glass fiber (Advanced Glassfiber Yarns) and carbon or graphite fiber.

[0049] The cross-section of fibers for use in the present invention may vary widely. Useful fibers may have a circular cross-section, oblong cross-section, or irregular or regular multi-lobal cross-section having one or more regular or irregular lobes projecting from the linear or longitudinal axis of the fibers. In particularly preferred embodiments of the invention, the fibers are of substantially circular or oblong cross-section and in the most preferred embodiments are of circular or substantially circular cross-section.

[0050] The fibrous network may be formed from fibers alone, or from fibers coated with a suitable polymer, such as, for example, a polyolefin, polyamide, polyester, polydiene such as a polybutadiene, urethanes, diene/olefin copolymers such as poly(styrene-butadiene-styrene) block copolymers, and a wide variety of elastomers. The composite fiber substrate element 18 may also include a network of a fibers dispersed in a polymeric matrix such as, for example, a matrix of one or more of the above referenced polymers to form a flexible composite. The composite fiber substrate may also include a network of fibers that is bonded together without the use of a matrix.

[0051] Useful organic fibers for this invention include aramid, (Kevlar®, Twaron®), polyethylene (Spectra Shield®), liquid crystal polymers (Vectran®), fiberglass, carbon, and M5®.

[0052] Useful inorganic fibers include S-glass fibers, E-glass fibers, carbon fibers, boron fibers, alumina fibers, zirconia-silica fibers, alumina-silica fibers and the like.

[0053] The fibers in composite fiber substrate 18 may be arranged in networks having various configurations. For example, a plurality of filaments can be grouped together to form twisted or untwisted yarn bundles in various alignments. The filaments or yarn may be formed as a felt, knitted, or woven (plain, basket, satin, and crow feet weaves, etc.) into a network, fabricated into non-woven fabric, arranged in parallel array, layered, or formed into a woven fabric by any of a variety of conventional techniques.

[0054] Composite fiber substrate/backing 18 may be more than one layer. In one preferred embodiment, composite fiber substrate/backing 18 has more than one layer, with the fibers of the layers arranged in a parallel array and having the longitudinal axis

of the parallel fibers aligned at a 90 degree angle with respect to the longitudinal axis of the parallel fibers in the adjacent layers.

[0055] Fibers having a tenacity equal to or greater than about 7 grams per denier, a tensile modulus equal to or greater than about 150 g/denier, and an energy to break equal to or greater than about 8 g/joule are preferred.

[0056] Fibers having a tenacity equal to or greater than about 25 grams per denier, a tensile modulus equal to or greater than 1000 g/denier, and an energy to break equal to or greater than about 20 g/joule are more preferred.

[0057] Fibers having a tenacity equal to or greater than about 30 grams per denier, a tensile modulus equal to or greater than about 1300g/denier and an energy to break equal to or greater than about 30g/joule are even more preferred.

[0058] Fibers of polyethylene having a tenacity equal to or greater than about 30 grams per denier, a tensile modulus equal or greater than about 800g/denier and an energy to break of at least about 35g/joule are most preferred.

[0059] In a preferred embodiment of the invention, for the SAPI plate requirements, the areal density of the backing is greater than 2.5 psf. The more preferred areal density of the backing is greater than 3.0 psf, and the most preferred areal density of the backing is greater than or equal to 3.2 psf.

[0060] Preferably, the composite fiber substrate 18 has a fiber content of at least about 75% by weight or by volume, a more preferred fiber content of more than about 80% by weight or by volume, and a most preferred fiber content exceeding about 85% by weight or by volume.

[0061] A preferred backing includes a network of fibers in a resin matrix. The resin type is any resin suitable for use in the making of a composite fiber substrate/backing 18e without departing from the spirit and scope of the invention. These resins include: phenolics, urethanes, epoxies, acrylics, polyesters, vinyl esters, liquid crystal polymers, and thermoplastic resins such as polyolefins, polyamides, and polyesters. Most preferred

polymeric resin materials are polyolefins, such as polyethylene, polypropylene, and the like, and polyamides, such as nylon 6 and nylon 66.

[0062] In one embodiment, the matrix, either resin, polymeric, or of another material, is rigid and has a tensile modulus of less than about 6000 psi (41,300 kPa) at 25°C. In one embodiment the composite fiber substrate 18 is rigid and has a tensile modulus of less than about 6000 psi (41,300 kPa) at 25°C.

[0063] A suitable backing includes a monolithic material or a hybrid of materials or resin types to allow the most efficient dissipation of energy from the projectile.

[0064] In a preferred embodiment of the invention, the metallic facing element 14 is bonded in intimate contact with the composite fiber substrate/backing 18, such as by use of adhesive layer 16. Preferably, the thickness of the adhesive layer 16 is between about 0.0005 inches and about 0.09 inches. Adhesive layer 16 may be any conventional adhesive without departing from the spirit and scope of the invention. Suitable adhesives include epoxies, polysulfides, polyurethanes, polyolefins, and acrylics. Acceptable results, however, are also possible by spacing the metallic facing element 14 at some distance from the composite fiber substrate/backing 18.

[0065] In one embodiment, an armor assembly 10 in accordance with the present invention includes a steel metallic facing element 14 having a hardness greater than about 40 on the Rockwell C scale, a thickness of no more than about 0.010 inches, and an areal density of no more than about 2.2 psf. The armor assembly 10 also includes a composite fiber substrate/backing 18 with an areal density greater than about 2.8 psf and a cover 22. The overall total thickness of the armor assembly 10 is no more than about 1.25 inches.

[0066] In one embodiment, the armor assembly 10 includes at least a metallic facing element 14, an adhesive layer 16, and a composite fiber substrate/backing 18 with a combined weight between about 4.5 psf and about 10.0 psf, and, prefereably, in the range of from about 4.5 psf to about 5.5 psf.

[0067] While a preferred embodiment of the invention is described in terms of use for a SAPI plate, this armor assembly has many applications where enhanced ballistic

production at minimum weight is required. This could include, for example, aircraft armor, helicopter armor, vehicle armor, helmets, and shields for civilian use at various areal densities, facing, and backing thicknesses. In addition to the ballistic and cost advantages of this armor, the armor assembly can be manufactured more easily, with all of the components of the armor assembly co-cured in one molding step, eliminating the need for post-assembly of the metallic facing element and the composite fiber substrate backing.

EXAMPLE

[0068] Hard steel having a nominal Rockwell C 57 hardness sold under the trade name Mars 300 and available from Usinor Industeel, was perforated with a staggered hole pattern 5mm diameter x 7mm between holes, heat treated, then ground from 125" to 0.08 inches thick. The resulting metallic facing element was placed in intimate contact with a high performance backing.

[0069] The backing raw material is sold by Honeywell Corporation under the trade name, Spectra Shield® Plus. One hundred and fifty-seven (157) layers of Spectra Shield® Plus were stacked and molded at a pressure of 3000 psi, at a molding temperature of 250 degrees F. until the center of the laminate reached 240 degrees F for fifteen minutes, and was then cooled under pressure. The perforated Mars 300 facing element was cut into 2"x 2" tiles and adhesively bonded to the face of the Spectra Shield® using adhesive sold under the trade name Spray 77, available from 3M Corporation. The resulting laminate was ballistically tested and yielded the following results. The core diameter of the M-855 bullet was 4.5mm while the perforated hole diameter was 5mm, 11% larger than the core of the projectiles. Testing was done per Mil STD 662F with all shots laser-aligned with the holes, which is considered the worst case scenario.

[0070]

Threat	Result
M-80 ball	No penetration
M-855	No penetration
LPS ball	No penetration
PS ball	No penetration

Table 3--Perforated Steel Test Results

[0071] While the present invention has been illustrated by the above description of embodiments, and while the embodiments have been described in some detail, it is not the intention of the applicant to restrict or in any way limit the scope of the invention to such detail. Additional advantages and modifications will readily appear to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details, representative apparatus and methods, and illustrative examples shown and descried. Accordingly, departures may be made from such details without departing from the spirit or scope of the applicant's general or inventive concept.